




Accelerating CPV Efficiencies to Create a Sustainable TW Platform

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SUNSHOT INITIATIVE

AWARDEE TECHNICAL SUMMARY

Title: Accelerating CPV Efficiencies to Create a Sustainable TW Platform

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Organization of Prime Awardee: NREL

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Background:
Photovoltaic (PV) efficiencies have increased as material quality has been optimized [1]. Multijunction solar cells measured under concentrated light have demonstrated efficiencies well above 40% [1,2]. Alta Devices demonstrated that optimization of the optical design of the solar cell could lead to further improvement of the efficiency by adding an excellent back reflector [3]. Although the potential benefits of "photon recycling" have been described for many years, the implementation of this concept into state-of-the-art solar cells, and especially into multijunction solar cells has been limited.

Objectives:
This project seeks to carefully define an understanding of how the optical design of a solar cell can increase the efficiency and how these benefits can be quantified. A special emphasis is placed on implementing photon recycling into each of the junctions of a multi-junction solar cell. This is challenging because subbandgap light must be efficiently transmitted to the underlying junction while light at the band edge must be confined in the active layers. In addition, the optical design innovation must provide a mechanism for conducting the electricity and heat out of the solar cell. Implementation of these concepts into multijunction structures targets a 48% efficiency for the final goal of the project.

Key Findings & Outcomes:
The project first focused on creating tools to quantify progress toward better using photon recycling in solar cell design. A model was developed to calculate the expected open-circuit voltage as a function of the optical properties of the solar-cell and the internal radiative efficiency of the active layers [4]. Figure 1 (left) shows the geometry used in the calculation. The reflectivity at the back is calculated as a function of angle and the optical properties of the layers. The external radiative efficiency, ηext, is dependent on the probabilities of absorption and escape (as shown in Fig. 1) according to eq. 1 [4]

$$\eta_{ext} = \frac{\eta_{int}\overline{P_{esc}}}{1-\eta_{int}\overline{P_{abs}}}. \quad (1)$$

The open-circuit voltage is a function of the external radiative efficiency [4] and examples of both the calculated and experimentally measured Voc are shown on the right side of Fig. 1.

Optimization of the optical design included addition of a high-quality reflector at the back of a thin cell (removed from the substrate) and elimination of parasitic absorption within the solar cells structure. Record-efficiency structures were measured for GaInP top cells and two-junction GaInP/GaAs cells under one-sun illumination [5] as shown in Fig. 2.

1. http://www.nrel.gov/ncpv/images/efficiency_chart.jpg.
2. http://www.soitec.com/en/news/press-releases/world-record-solar-cell-1373/.
3. B. Kayes, H. Nie, R. Twist, S. Spruytte, F. Reinhardt, I. Kizilyalli, and G. Higashi, "27.6% Conversion efficiency, a new record for single-junction solar cells under 1 sun illumination" 37th PVSC (2011).
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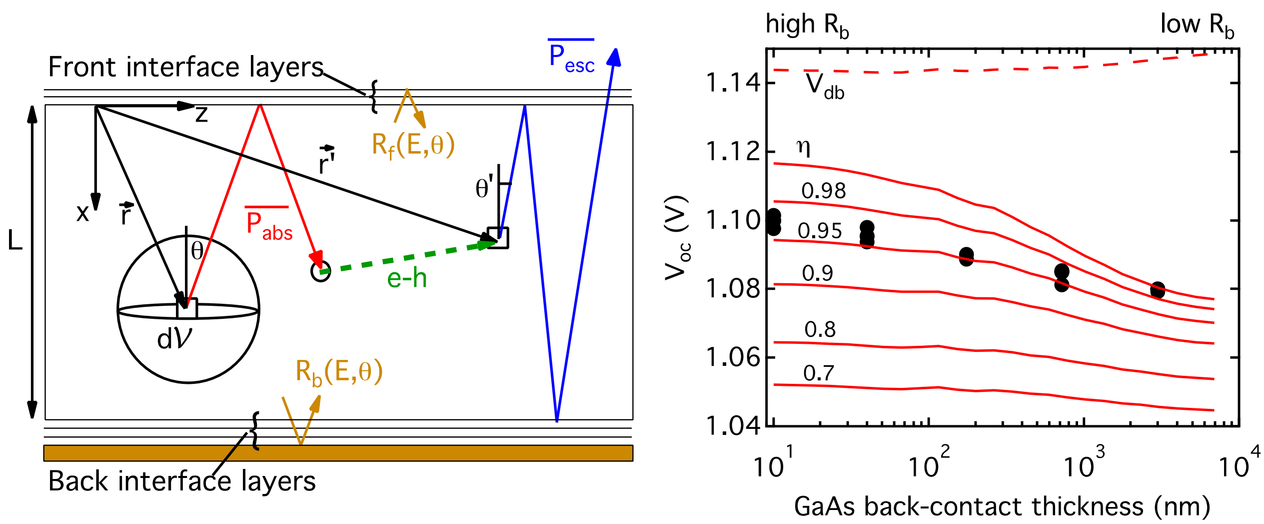

Fig. 1. (Left) The colored lines represent the different processes that an emitted photon can undergo in the structure: the red line shows a photon emitted at $\vec{r}$ that is re-absorbed after one reflection at the front; the blue line shows a photon emitted at $\vec{r}'$ that escapes after two internal reflections; the green dashed line represents diffusion of an electron. The yellow arrows at the top and bottom illustrate the effective Fresnel reflection coefficients. (Right) Modeled (lines) and measured (points) behavior of V_{oc} for structures with varying thickness of the back contact layer. The active layer thickness was nominally 2 µm. The solid red lines represent different values of the internal luminescent efficiency $\boldsymbol{\eta_{int}}$. The dashed line at the top shows the modeled detailed balance limit for the V_{oc}, V_{db}

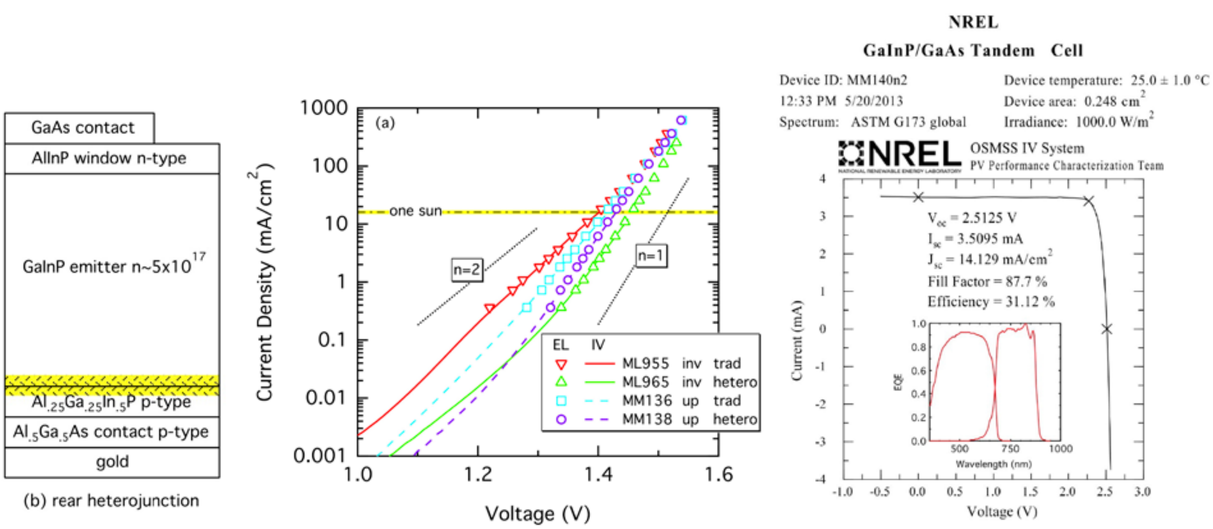

Fig. 2. (Left) Structure of GaInP cell grown inverted on the substrate, back reflector applied, and removed from substrate [5]. (Middle) Dark current as a function of voltage for multiple GaInP cells [5] (Right) I-V and external quantum efficiency for GaInP/GaAs cell [6].

References & Resources:

6. M. Steiner, J. Geisz, I. Garcia, D. Friedman, A. Duda, W. Olavarria, M. Young, and S.Kurtz, “Effects of internal luminescence and internal optics on the Voc and Jsc of III-V solar cells,” IEEE J. PV, **3**, p 1437 (2013).

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• J. Geisz, Presentation at Spring MRS 2013 "The Role of Optical Emission in High Performance III-V Solar Cells", Inter. Conf. on InP and Related Materials, 2012 "III-V Semiconductors for High-Efficiency Multijunction Photovoltaics"

• I. García, J. Geisz, M. Steiner, J. Olson, D. Friedman, and S. Kurtz, "Design of Semiconductor-based Back Reflectors for High Voc Monolithic Multijunction Solar Cells," Proc. 38th IEEE PVSC, pp. 002042 - 002047 (2012).

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